EFFECTIVE CROSS SECTION FOR THE INELASTIC COLLISIONS OF SLOW ELECTRONS WITH CESIUM ATOMS IN THE PRE-THRESHOLD REGION[1)]

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The "electron trap" method[5] was used to measure the cross section for the excitation of the cesium atom, by electron impact, to the $6p_{1/2,\,3/2}$ and $7p_{1/2,\,3/2}$ levels in the pre-threshold range of energies. For the former level, the slope of the initial rectilinear part of the curve was 1.5×10^{-14} cm²/eV. A comparison is made between the measured cross sections for the inelastic collisions and the results of theoretical calculations,[1,2] as well as with the total cross section for the interaction of electrons with cesium atoms.[8]

THE steadily increasing use of cesium in various branches of physics and technology requires a comprehensive investigation of its properties, in particular, the cross sections for the interaction of electrons with cesium atoms. While the cross section for the elastic collisions in this system can be regarded as experimentally determined over a fairly wide range of electron energies, there is hardly any information on the inelastic interactions. A theoretical discussion of the excitation of the cesium atom by electron impact to the level corresponding to the 6s–6p transition was recently published.[1,2] The problem was investigated experimentally in [3], where the relative excitation function of the cesium atom under electron impact was determined by an optical method, but the absolute values of the cross sections were not found. The short communication[4] gives only the maximum value of the total cross section for the inelastic collision of an electron with a cesium atom, determined indirectly from the measurement of the electron drift velocity in a mixture of cesium and argon.

These very limited data on the inelastic interaction of electrons with cesium atoms have stimulated us to extend the investigation of this problem, because further progress in the study of the physical properties of cesium plasma depends on its solution. Since cesium plasma has quite a low electron temperature (of the order of 3000° K), it is important to know the cross section for the excitation of cesium in the pre-threshold range of electron energies, where the excitation function has usually a nearly rectilinear dependence.

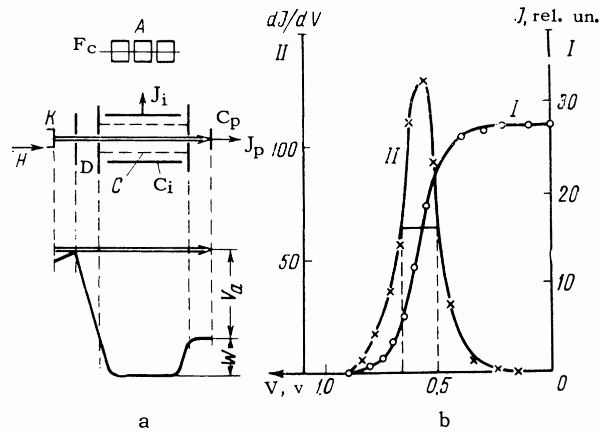

FIG. 1

To solve this problem, we used the recently developed[5] "electron trap" method to detect electrons inelastically scattered in single collisions. This method has a high resolving power and is convenient for the measurements of the cross sections for the inelastic collisions in the pre-threshold range of energies. The apparatus we used is shown schematically in Fig. 1a.

In this apparatus, the rectilinear motion of electrons, emitted by a flat heated oxide cathode, was ensured by a small aperture (0.05 cm in radius) in a plane electrode D and by a longitudinal magnetic field **H**. The collision chamber C was in the form of a cylinder having a length L = 3.8 cm and a radius R = 0.6 cm. Its curved surface was in the form of a grid made of twenty thin tungsten wires of 0.0025 cm radius, equally spaced along the generators of the cylinder. The geometrical

1)Presented at the Third All-union Conference on Physics of Electronic and Atomic Collisions, Khar'kov, 1965.

transparency of this grid was 97%. At the flat ends, the collision chamber was closed by tantalum disk electrodes with diaphragms (radius $r_c = 0.1$ cm) for the admission of the electron beam.

The collector C_i for the inelastically scattered electrons—a tantalum cylinder 0.8 cm in radius and 3.8 cm long—was placed coaxially with the collision chamber. Behind the collision chamber, we placed a collector C_p for the primary beam electrons, which was in the form of a Faraday cylinder. In the working position, the grid C and the collector C_p were at the same potential V_a, which was positive with respect to the electrode D. A potential well of depth W was produced in the collision chamber by the penetration, through the grid, of an electric field applied between the electrodes C and C_i.

Thus, the energy of the exciting electrons in the collision chamber should be $V_a + W$. The electrons suffering inelastic collisions and energy losses in the range from V_a to $V_a + W$ are captured by the potential trap and can only reach the collector C_i. It is easy to see that, on the one hand, the energy spread of the measured excitation function is governed by the depth of the potential well W and, on the other hand, it is necessary to have, in this range of energies, only one (best of all, the lowest) energy state of the atom, i.e., in this sense, the electron trap method is very convenient for solving our problem.

The distribution of the potential in the collision chamber was determined by modeling in an electrolytic tank. It was then found that W = const over 75% of the length of the collision chamber and over the whole of its radius, and that the penetration of the grid by the electric field was $\eta = W/V_{ci} = 0.45$, i.e., to produce a potential well W = 1 V between the grid C and the collector C_i, it was necessary to apply a voltage $V_{ci} = 2.2$ V. During the measurements, the depth of the potential well was checked by the method described in [5].

It must be emphasized that an electron in the primary beam, which has suffered an elastic collision with a cesium atom and lost in this process a sufficient proportion of its longitudinal momentum, may also be captured by the electron trap. The stronger the anisotropy of the angular distribution of the elastically scattered electrons, the less likely is such capture. The following conditions must be satisfied in order that an electron scattered elastically at an angle α should not be captured by the trap:

$$m(v\cos\alpha)^2/2 \geqslant eW, \qquad \rho = \frac{mvc}{eH}\sin\alpha \leqslant r_c.$$

The second of these governs the necessary minimum value of the magnetic field H_{min}, which we were unable to estimate quantitatively since we did not know the nature of the angular distribution of electrons scattered elastically by cesium atoms. Therefore, the value of this field was determined experimentally from the optimum value of the current to the collector C_p and from the lowest background current to the collector C_i due to the elastically scattered electrons, at electron beam energies slightly lower than the first excitation potential.

On the other hand, the value of the magnetic field H had an upper limit for the following reasons:[5]

1. A slow electron, obtained after an inelastic collision with a cesium atom and captured by the trap, may reach the collector C_i only by diffusion in the magnetic field. The time taken by an electron to diffuse to the boundary of the collision chamber is given by the expression

$$\tau = 0.26\, eH^2R^2 / c^2 mV\nu_c,$$

where V is the electron energy in volts, and ν_c is the frequency of its collisions with cesium atoms. When H is increased, this time may increase so much that the space charge due to captured electrons may become considerable.

2. The value of the applied magnetic field should not alter greatly the mean free path of electrons in cesium vapor.[6]

In our experiments, the primary beam current did not exceed the value $J_p = 8 \times 10^{-8}$ A, and the current due to the inelastically scattered electrons received by the collector C_i was within the limits $J_i = 1.5 \times 10^{-9} - 3 \times 10^{-8}$ A. To obtain the single-collision conditions, we used low cesium vapor pressures—about $(2-5) \times 10^{-4}$ mm Hg. The magnetic field that we used, H = 50–70 Oe, satisfied all the requirements listed above. In particular, by determining the value of τ from the experimental conditions, we were then able to find, using a method given in [7], the value of the potential drop ΔV in the center of the collision chamber, due to the influence of the space charge of the captured electrons. It was found that $\Delta V < 0.1$ V. Moreover, the absence of a space charge of the captured electrons was indicated by the constancy of the current J_i in the range of values of H close to 50–70 Oe.[5] However, at H > 150–200 Oe, the current J_i began to decrease when H was increased, which, together with an estimate made using the method given in [7], indicated the presence of a considerable space charge of the captured electrons.

Our use of a heated oxide cathode, working under pronounced underheating conditions ($T_{cath} \approx 600-700° K$), should have ensured strong monokineticity of the electron beam which excited the cesium atoms. To determine this monokineticity, we recorded, at the collector C_p, the retardation current-voltage characteristics for various values of the accelerating potential applied between the electrodes D and C (for example, curve I in Fig. 1b). The scatter of electron energies, determined from the half-width of differentiated retardation curves of similar type (curve II in Fig. 1b), did not exceed 0.15–0.2 V. Allowance for the contact potential differences between electrodes in our apparatus, as well as the determination of the absolute electron energy, were confined to the shift of the threshold of the excitation function, which was made to coincide with the energy known from the optical measurements, i.e., to coincide with 1.4 V.

We introduced into our experimental tube a diode with a heated tungsten cathode (shown in the upper part of Fig. 1a; F_c is a tungsten filament cathode and A is the anode) in order to determine accurately the concentration of cesium atoms. By measuring the ion saturation current, due to the thermal ionization of cesium atoms on the heated tungsten surface, we determined the concentration of cesium atoms.

A typical curve showing the dependence of the ratio of the current J_i of the inelastically scattered electrons reaching the collector and the current J_p of the primary beam on the electron energy in this beam is shown in Fig. 2. The initial rise of the curve corresponds to the resonance excitation function of the cesium atom to the unresolved, in our experiments, doublet level $6p_{1/2,\,3/2}$ in the pre-threshold region. The beginning of the descent of this curve is governed by the magnitude of the potential well W. By increasing the depth of the well, we measured the cross section for the excitation of the cesium atom to the level $6p_{1/2,\,3/2}$ between the threshold and the electron energies of 2.5 eV. The second peak in the curve of Fig. 2 represents the excitation of the cesium atom to the $7p_{1/2,\,3/2}$ level. The presence of the background current at the primary electron energies lower than the excitation threshold is associated, as mentioned above, with the capture of the elastically scattered electrons in the trap. This, as shown in Fig. 2, should not lead to great errors in the determination of the cross section for the excitation of the atom to the $6p_{1/2,\,3/2}$ level.

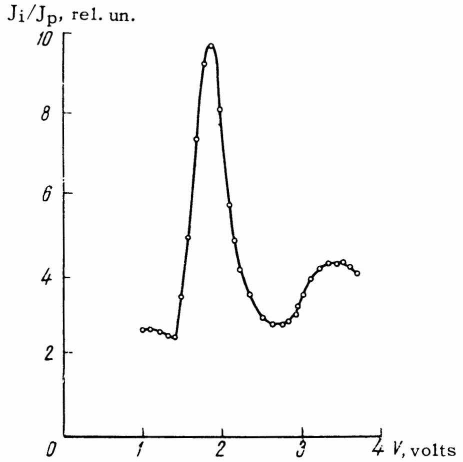

FIG. 2

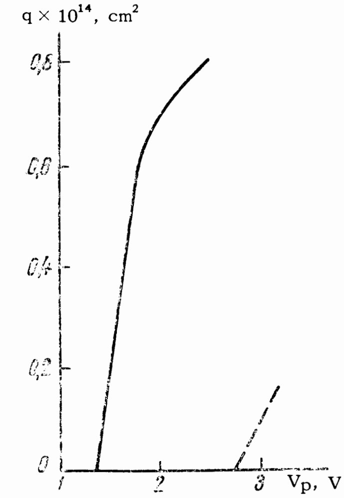

FIG. 3

From a family of curves, similar to that shown in Fig. 3 and obtained for various depths of the potential well W, we deduced the dependence of the value of the cross section for the inelastic collisions of electrons with cesium atoms on the energy of the exciting electrons (Fig. 3); the continuous curve in Fig. 3 represents the resonance excitation of cesium to the first doublet level ($6s_{1/2} - 6p_{1/2,\,3/2}$) and the dashed curve represents the excitation to the second level ($6s_{1/2} - 7p_{1/2,\,3/2}$). The slope of the initial rectilinear part of the first, main curve is 1.5×10^{-14} cm^2/eV.[2)]

Figure 4 compares our cross section (in units of πa_0^2, where a_0 is the radius of the first Bohr orbit; the scale is logarithmic along both axes) for

[2)]L. Shimon and I. Zapesochnyĭ reported, at the Third All-union Conference on Physics of Electronic and Atomic Collisions (Khar'kov, 1965), the first results of quantitative measurements of this cross section by an optical method, which differed little from our data.

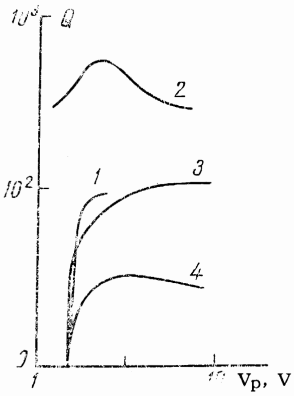

FIG. 4

excitation to the $6p_{1/2, 3/2}$ level (curve 1) with the total cross section for the interaction of electrons with cesium atoms (curve 2) reported by Brode.[8] So far, Brode's work is the only one in which measurements of the total cross section of this interaction were carried out using the single-collision method. From comparison of curves 1 and 2, we can determine the probability of the excitation of the cesium atom to the $6p_{1/2, 3/2}$ level. Curve 3 in Fig. 4 gives the results of the semi-classical calculation of Hansen,[1] which is in reasonable agreement with our experimental data. The results of the classical calculation, carried out by Sheldon and Dugan[2] and represented by curve 4 in Fig. 4, are in much poorer agreement with our results. Finally, we ought to mention that the value $q_{max} \approx 5 \times 10^{-15}$ cm^{-2}, obtained by Nolan and Phelps,[4] is much smaller than our value.

In conclusion, the authors express their profound gratitude to Prof. N. D. Morgulis for directing this investigation.

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